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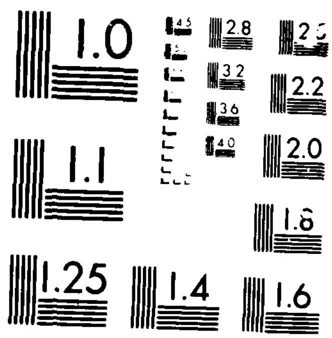
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AIR FORCE

HUMAN RESOURCES

LOW-COST AVIONICS SIMULATION FOR AIRCREW TRAINING

AD-A169 198

Bernell J. Edwards

OPERATIONS TRAINING DIVISION
Williams Air Force Base, Arizona 85240-6457

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This report has been reviewed and is approved for publication.

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The purpose of this experiment was to determine the training effectiveness of a microcomputer-based avionics system trainer as a cost-effective alternative to training in the actual aircraft. Aircrew members learned the basic operation of the Fuel Savings Advisory System (FSAS), a computerized fuel management system for C-141 and C-5A aircraft. The 26 subjects participating in the experiment were operationally qualified C-141 pilots with no prior knowledge of FSAS. They were randomly assigned either to an experimental group ($n = 13$) to receive training via the microcomputer-based, self-tutorial trainer, or to a control group ($n = 13$) to be trained by an instructor on the flight deck of an FSAS-equipped C-141 aircraft. Both groups were trained to criterion proficiency on eight basic FSAS tasks. Time required to achieve proficiency was measured for all subjects on all tasks. As a result of training, the experimental group exceeded the specified proficiency standard, achieving a mean proficiency rating across the eight tasks which was significantly ($p < .001$) superior to that of the control group. A transfer effectiveness ratio was applied to assess transfer of training from the experimental trainer to the criterion task in the aircraft. The obtained ratio of 1.04 indicated the

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experimental trainer was fully as effective as aircraft training for the tasks. This yielded a cost benefit ratio of 4.76 to 1 (aircraft training cost versus microcomputer trainer cost). This result demonstrates the potential benefit of the experimental trainer to reduce training cost. For example, if applied to the training of all current C-141 and C-5A aircrews in basic FSAS procedures, seven such trainers used as substitutes for training in the actual aircraft would achieve an estimated cost avoidance of more than 8 million dollars.

SUMMARY

This report documents the evaluation of a low-cost trainer as a substitute for aircraft-based training. The training was provided to C-141 pilots to train them to perform several procedural tasks associated with the operation of the Fuel Savings Advisory System (FSAS). This system is being retrofitted on C-141 and C-5A aircraft. Operational aircrews must be trained to operate the FSAS in order to be mission qualified. This report documents an experiment in which trainees learned to operate the FSAS, either in the aircraft or via the low-cost alternative. Results showed both groups required the same amount of training time to learn to perform the tasks. Thus, the low-cost alternative was shown to be an effective substitute for the aircraft for training the FSAS tasks. A cost analysis comparing the two training methods shows the low-cost trainer is capable of avoiding more than 8 million dollars in training costs if it is employed to train current C-141 and C-5A aircrews in the FSAS tasks.

PREFACE

This effort represents a portion of the research and development (R&D) program of the Air Force Human Resources Laboratory (AFHRL) for Technical Planning Objective 3, the thrust of which is Aircrew Training. The general objective of this thrust is to identify and demonstrate cost effectiveness in training Air Force aircrew members. More specifically, the effort was part of the R&D conducted under the Aircrew Training Effectiveness subthrust, which has as its goal the provision of a technology base for improving the effectiveness and efficiency of training combat aircrews. The present effort was conducted as a part of Work Unit 1123-25-01, Special Function Trainer Technology. The research was accomplished in cooperation with the Military Airlift Command (MAC) in accordance with terms of a Memorandum of Agreement (MOA) between HQ MAC/DOT and AFHRL. Under the agreement, MAC will produce one or more experimental special-function trainers and AFHRL will provide consultative services to MAC for the design, development, and evaluation of the trainers. The purpose of the present effort was to evaluate the training effectiveness of one such special function trainer developed by MAC to teach avionics procedural skills to aircrew members.

The author acknowledges the design and development efforts of MAC personnel which underlie the present report. Specifically acknowledged is the work of: Lt Col Joe Burch, HQ MAC/DOT, who provided the impetus for MAC's investigation of special function trainer technology; Capt John Queern, HQ MAC/DOOAE, who developed TEACHER, an instructional authoring language that made possible the development of computerized training sequences by a MAC subject-matter expert without the need for a professional computer programmer; Capt Frank Murray, HQ MAC/DOT, who developed G-TEACHER, making possible the simulation of the avionics system required for the present effort, and who also provided the extensive documentation of training cost data contained in Appendix B of this report; and Maj Jacob Miller, 63 MAW/DOT, who developed the Fuel Savings Advisory System (FSAS) training syllabus, developed and validated the experimental software for the special function trainer, and provided the field training data in accordance with the requirements for the present analysis and evaluation.

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LOW-COST AVIONICS SIMULATION FOR AIRCREW TRAINING

I. INTRODUCTION

Background

The Military Airlift Command (MAC) is in the process of retrofitting its C-141 and C-5A aircraft with a Fuel Savings Advisory System (FSAS) designed to maximize fuel efficiency. As aircraft are modified, all operational aircrews must be trained to operate the new fuel management equipment. Pilots, navigators, and flight engineers must be able to perform FSAS tasks as part of mission requirements. Moreover, aircrew members must be able to operate the system with some proficiency before attempting to operate it during flight. Until recently, MAC was faced with the problem of bringing its aircrews to basic proficiency on FSAS without the aid of ground-based training equipment. The alternative was to use the aircraft itself on the ground for the initial proficiency training. Like all operational avionics systems, FSAS would be very expensive to replicate/simulate if actual spare instrument panels were procured for use with ground-based hardware/software for training purposes, although such an option has been considered and is discussed later in this report.

For this reason, another alternative was proposed: simulation of FSAS using inexpensive microcomputer-based graphics and software. Such a system would be designed to bring the aircrew member to a level of proficiency sufficient to permit safe operation of FSAS under actual flight conditions. MAC recently developed such a system and the evaluation of its effectiveness as a training device by AFHRL is the subject of the present report.

Related Research

Although there has been much recent interest in the use of microcomputer-based devices for various military training applications, there are relatively few empirical experiments assessing training effectiveness. Numerous reports document the application of computer-assisted instruction (CAI) in various forms for various subject matters (usually academic). However, few studies have investigated applications in which the computer itself is used both as an instructor and a simulator to provide guided practice, leading to on-task competencies. Johnson, Munro, and Towne (1981) and Towne and Munro (1981) have reported the transfer of performance competencies for electronic equipment repair skills, using computer-assisted, two-dimensional simulation, to performance of these tasks on actual (three-dimensional) equipment. Cicchinelli, Harmon, and Keller (1982) suggested that low-cost, two-dimensional simulations were appropriate in training contexts for replicating many of the physical and functional characteristics of the actual equipment. Massey (1985) found that touch-actuated video screen displays of equipment control components were equal in training effectiveness to the actual equipment controls for teaching basic equipment operations to avionics systems maintenance trainees. In the same experiment, Massey found the interactive graphics displays were superior to the actual equipment for teaching avionics troubleshooting skills to maintenance trainees. These studies support the use of small computer systems for specific types of procedures training.

There is some empirical evidence to support the training effectiveness of microcomputer-related technology in aircrew task simulation contexts. Pohlman and Edwards (1983) demonstrated the superiority of a computer-aided, two-dimensional graphics simulation over illustrated textual materials in the transfer of cockpit procedural skills to a flight simulator. Brooks (1985) reported the effectiveness of a microcomputer-based, two-dimensional graphics system for the acquisition of aircrew procedural skills in radar warning receiver (RWR)

avionics system operations. Hageman (1983) reported the effectiveness of transferring procedural task competencies in aircrew avionics systems from a two-dimensional computer graphics system to operation of actual aircraft avionics systems.

Purpose of Experiment

The present experiment was undertaken to determine the training effectiveness and potential cost savings of a microcomputer-based, avionics procedures trainer as applied to a pressing Air Force training requirement. The purpose of the empirical evaluation was twofold: (a) to determine the feasibility of employing a low-cost, part-task trainer as a substitute for in-aircraft avionics training, and (b) to provide empirical training effectiveness data as the basis for cost effectiveness attainable with a low-cost microcomputer device. The scope of training was limited to on-task competencies for basic FSAS procedures. The experiment reported herein assessed the transfer of training from the experimental device to operation of the aircraft equipment.

II. METHOD

Design of Computer-Based Instruction

The design and development of instructional software was accomplished using TEACHER (in Microsoft Basic), an English-language authoring software program developed by Capt John Queern, HQ MAC/DOOAE[1]. TEACHER was designed specifically for subject-matter experts who lack computer programming skills. The basic TEACHER program was extended to accommodate interactive graphics for the FSAS trainer by Capt Frank Murray, HQ MAC/DOT, and renamed G-TEACHER. It is compatible with the Honeywell EXPER language and similar in instructional power and flexibility to the PILOT authoring system.

A systematic approach was used in the design of the training software. Task analysis of the FSAS was conducted, from which a set of training objectives and skill proficiency requirements were developed. Further analysis resulted in the identification of detailed procedures for each phase of FSAS familiarization and basic operation. These were further organized into a series of eight proficiency modules or lessons; i.e., one lesson for each of the tasks required for FSAS initial training. The tasks were (a) loading present position, (b) loading way points, (c) making changes in initial way point data, (d) loading TACAN data, (e) loading takeoff data, (f) verifying takeoff data, (g) performing way point changes, and (h) selecting maximum rate of climb and "coupling" FSAS to the autopilot. The training objective was to get the student "on-task" as soon as possible by engaging the student interactively with FSAS, as simulated by the microcomputer-based software. Proficiency measures were specified behaviorally, and practice routines were designed into the software for each task. Lessons were developed as stand-alone, self-paced instruction.

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[1]Capt Queern developed TEACHER while assigned to HQ MAC/DOOAE as an Air Force Reservist. It is of interest that the developmental work was accomplished during Capt Queern's off-duty time, and TEACHER was informally donated to the Military Airlift Command. The software was originally written in microsoft basic for any CP/M-compatible computer. The program contained no graphics input or output capabilities nor multi-screen or multiple input source capabilities. All of the latter capabilities were developed by Capt Frank Murray, who named the graphics-enriched version of the program G-TEACHER (pronounced Gee-teacher) for graphics version of TEACHER.

Training Development/Delivery System

Courseware was developed on a North Star Horizon microcomputer fitted with a 12-inch monitor and keyboard and a Micro Angelo graphics board. The monitor with lightpen (later fitted with a touch screen) was used to display the simulated FSAS instrument panel. Tutorial text was displayed on a separate monitor. An FSAS subject-matter expert, using the authoring language, developed all of the lesson materials.

The same system was used for both training development and training delivery. Each student sat at a table containing the computer equipment and monitors. Simple instructions were provided on how to initiate lessons by making minimal inputs via the computer terminal keyboard. Text displayed on the monitor explained the lessons and prompted student responses. The FSAS control panel (slightly enlarged from actual size) was displayed on the graphics monitor, and the students could simulate operating it by touching the display screen while they followed the text instructions (Figure 1). Student inputs were judged for correctness by the system, and remedial prompting was provided as required. The students received explanations and guided practice on each task. Self-tests permitted the students to assess their own competency on each task before proceeding to the next lesson.

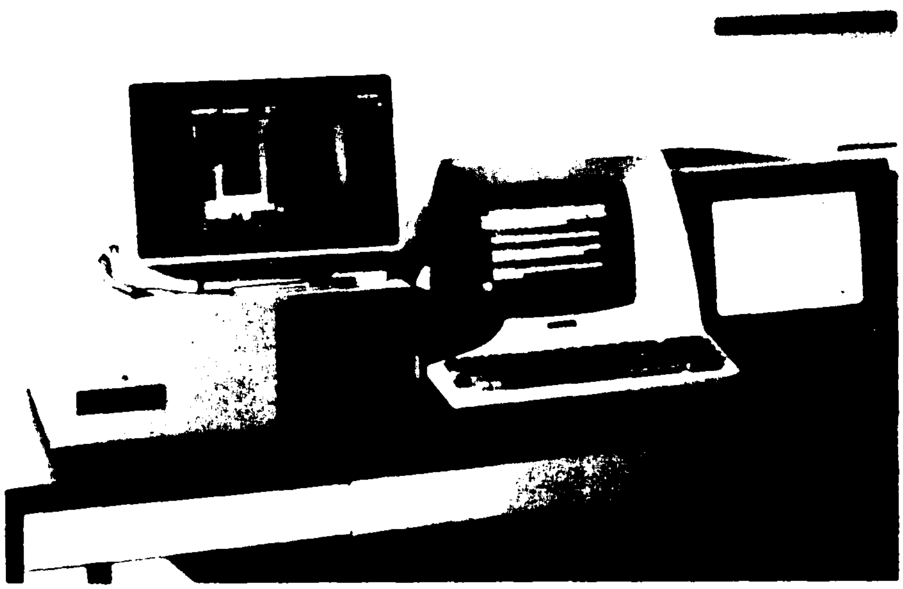

Figure 1. Low-Cost Avionics Trainer.

Software Validation. Eleven C-141 pilots participated in a tryout of the experimental software. During these tryouts, close dialog was maintained between pilots and course developers in order to maximize the software revision process. Although no extensive changes were found necessary, nearly all lessons required slight modifications.

To check the effectiveness of the computer-based training, students in the tryout group, following training on the experimental device, were taken to an FSAS-equipped C-141 to see if they could correctly execute tasks on the actual equipment. Although this performance check was administered informally, it was clear that students were able to perform the tasks.

As part of the tryout, each student answered a questionnaire about the experimental training. The questionnaire was included in the computer program at the end of the eight lessons. Respondents were asked to rate various aspects of the experimental training. A summary of the responses to the questionnaire is shown in Table 1, and a copy of the questionnaire format is contained in Appendix A.

Table 1. Trainer Tryout Questionnaire Summary (N = 11)

Rating scale		Mn rating
Trainer Ease of Use for:	1-5 (hard-easy)	
Text Information		2.9
Light Pen Use		1.0
Keyboard Use		3.7
Graphic Displays		3.2
Trainer Usefulness for FSAS Task for:	1 - 5 (not useful - very useful)	
Basic Information		4.3
FSAS/INS Functions		3.8
INS MODE Keys and Functions		3.5
LOAD MODE Functions		3.9
NAV MODE Functions		4.3
FLT MODE Functions		4.3
PLAN MODE Functions		4.1
RADAR Display Functions		4.1
Amount of Training Provided for:	1 - 5 (not enough - too much)	
Basic Information		3.5
FSAS/INS Functions		3.3
INS MODE Keys and Functions		3.3
LOAD MODE Functions		3.3
NAV MODE Functions		3.1
FLT MODE Functions		3.1
PLAN MODE Functions		3.1
RADAR MODE Functions		3.0
Usefulness for Training		
Other Types of Tasks:	1-5 (not useful - very useful)	3.8

In general, the opinions of pilots in the tryout group indicate the acceptability of the trainer, and aircraft testing confirmed training effectiveness. Students were also asked to comment about any problems or ideas for lesson improvement. Suggestions were reviewed and included in revised versions of the software as appropriate. As can be seen from Table 1, the major problem that students encountered in the initial version of the trainer was use of the lightpen. Many found it awkward to manipulate and inaccurate for data inputs via the graphics screen. When the lightpen was replaced with a touchscreen, students could input data by finger touch and this modification eliminated virtually all inaccuracies in student responding.

Experimental Procedure. Twenty-six C-141 pilots participated as subjects in the empirical validation of the FSAS trainer. They were operationally qualified, with varying flying experience in ranks from second lieutenant to captain. None had prior experience or training on the FSAS.

All subjects received general information about the FSAS in a classroom lecture before participating in the experimental training. The content and time of lectures were controlled. The same instructor and lesson material were used for all trainees.

Subjects were randomly assigned to either an experimental group (n = 13) to receive training via the experimental device, or to a control group (n = 13) to receive training on the flight deck of an FSAS-equipped C-141 aircraft.

Subjects assigned to the experimental group were instructed to follow the instructions contained in the computer program by practicing and self-testing on each task until they were confident they could execute it correctly and unaided in the aircraft. Upon completing the computerized instruction, students were taken to the C-141 aircraft flight deck and given a criterion test on each of the eight tasks using the actual FSAS equipment. Experimental group subjects were tested and remediated as required on each task in the aircraft until achievement of criterion proficiency.

Subjects assigned to the control group received FSAS training in the aircraft only. They received the same lesson content and task sequence as the computer-trained experimental group. During the instructional phase, students received guided practice on each of the tasks. They were instructed to indicate when they were confident they could perform each of the tasks unassisted. They were then tested and remediated until they achieved criterion proficiency. Thus, the content and sequence of training and testing were standardized and controlled for both groups.

Task Proficiency Criteria. A standard (MAC) proficiency rating scale, based on behavioral descriptors, was used by the instructor in evaluating the performance of both groups on the criterion test. A scale from 0 to 4 was defined as follows: (0) Cannot complete the task; (1) Has difficulty and requires assistance; (2) Completes the task with minimal prompting; (3) Completes the task without assistance; and (4) Completes the task quickly and accurately.

The minimal proficiency rating of 3 was specified as the performance criterion for each of the eight FSAS tasks. Times required for the instructional and testing portions of the training were recorded for all students in both groups. All subjects were tested and rated by the same instructor to preclude interrating bias. The total training time (time on task) required to achieve criterion proficiency by each subject on the eight tasks was used as the dependent measure of training.

Experimental Paradigm

A Roscoe (1971, 1972) transfer effectiveness ratio (TER) was used to assess training effectiveness as a function of training time to criterion performance. This design provides an empirically based determination of the transfer of training from the experimental trainer to the aircraft.

III. RESULTS

Table 2 displays a comparison of training times for the experimental and control groups. The experimental group required an average of 116.54 minutes per subject to complete FSAS training on the microcomputer system. Experimental subjects required an average of 30.15 minutes to demonstrate criterion proficiency on the aircraft FSAS. Average total training time for the experimental group was 146.69 minutes. The control group received all FSAS training in the aircraft. The mean training time for this group was 120.24 minutes and they required an average of 30.76 minutes to demonstrate proficiency during the testing phase, for an average total time per subject of 151.00 minutes. None of the differences between the mean time comparisons between the two groups, as shown in Table 2, was significant statistically.

Table 2. **Mean Training Time (Minutes) to Criterion Proficiency as a Function of Two Training Methods for Eight Procedural Tasks**

	Required training time	Required criterion testing time	Total time on task
Experimental (N = 13)	116.54	30.15	146.69
Control (N = 13)	120.24	30.76	151.00

Transfer of Training. Applying the TER to the obtained training data, the following outcome is achieved:

$$T_{er} = \frac{\overline{C} - \overline{X}}{\overline{PTT_X}}$$

Where:

$\overline{C}$ = control group mean time (minutes) to criterion performance using actual aircraft equipment.

$\overline{X}$ = experimental group mean time (minutes) using actual aircraft equipment (after pre-training).

$\overline{PTT_X}$ = experimental group mean training time (minutes) using microcomputer-based part-task trainer prior to training in aircraft.

: :

$$T_{er} = \frac{151 - 30.15}{116.54} = 1.04$$

The obtained TER of 1.04 indicates that there is slightly better than a one-to-one correspondence between the effectiveness of the training provided by the experimental trainer and that provided in the aircraft. In short, the data indicate the trainer was fully as effective as the ground-based aircraft (with instructor) for teaching familiarization and basic operational skills associated with FSAS.

Proficiency Acquisition. While minimal proficiency was a rating of 3, if the subject was able to complete the task quickly and accurately without prompting, a rating of 4 was given for the task. The experimental group exceeded the control group on the ratings. The mean proficiency rating for the experimental group across the eight tasks was 3.50 (SD = .20) compared to a mean of 3.18 (SD = .13) for the control group. This difference is significant at the .001 level of statistical probability ($t = 4.85$).

Cost Effectiveness

The transfer-of-training effectiveness of the experimental system shows the replacement value of the experimental device for the aircraft and provides the required empirical basis for cost comparisons. Cost data comparisons are predicated on the assumption of a one-to-one replacement value of the trainer for the aircraft for FSAS initial training.

Cost comparisons are based on several assumptions. For purposes of presentation, cost comparison data are only summarized in this section of the report. Appendix B provides a full exposition of the assumptions and derivation of cost formulas.

Aircrew Training. The first assumption is that cost analysis will be limited to the training of the current population of aircrew members in the active and reserve flying units plus crew members attached to those units. Thus, training costs are applied to a training period of less than 2 years. Additional savings could be achieved if training on the experimental system were extended beyond current aircrews.

A total of 4,247 aircrew members are to be trained for the C-141, including pilot/copilot, navigator, and flight engineer positions. The total number of C-5A aircrew members to be trained is 1,212, for a grand total of 5,459 crew members to be trained on FSAS.

Training Hours. A standard factor of 2.5 training hours per student is assumed for both methods of instruction. This figure is derived from empirical findings of the present transfer-of-training data. The 2.5-hour figure is an approximated average from the total training time required per student for both the experimental and control groups. Aircrews in both the experimental and control conditions were trained in pairs, and the assumption for cost comparisons is that this practice would be used for future FSAS training. Thus, the derivation of the total training hours is the total aircrew members to be trained x 2.5 hours divided by 2 hours. The total training hours required for C-141 aircrews is 5,309 and, for the C-5A, it is 1,515.

Aircraft-as-Trainer Costs. The use of an aircraft equipped with the FSAS system would be required in lieu of no other training device. MAC classifies the use of aircraft for ground training purposes as lost opportunity of revenue and charges for aircraft time accordingly (Appendix B). Cost is calculated on an hourly basis with a 24-hour ceiling cost. Taking into account the expected training time and scheduling efficiency, it is estimated that a total of no more than six students could be trained in an available aircraft during a 24-hour period. The derived training cost per student for FSAS training in the C-141 is $1,720.17 and, for the C-5, it is $2,815.00.

Instructor/Developer Costs. The cost of instructor time and software developer time is derived applying a standard hourly rate of $27.11 for a rated Air Force officer.

Microcomputer Training Costs. Costs associated with the use of the experimental trainer used in the present study are subdivided into hardware acquisition, initial spare systems, and operating and maintenance costs (electricity, hardware and software maintenance, and magnetic discs). The costs shown reflect the acquisition of seven systems to train both C-141 and C-5A aircrew members.

Courseware Costs. Courseware costs associated with aircraft training are for development of training syllabus materials to be used by instructors in the aircraft. Courseware costs for the microcomputer version of FSAS training are for the development of FSAS simulation and training software. Courseware costs are computed at the standard manpower rate (rated officer = $27.11 per hour).

Cost Comparisons

Training Method 1 - Aircraft C-141 Costs		Method 2 - Microcomputer Trainer	
Aircraft Use Cost	$7,305,562.00	Hardware	$50,400.00
Courseware	542.20	Courseware	8,675.20
Instructor Time	143,926.99	Oper/Maint Costs	3,775.72
C-141 Totals	$7,450,031.19	Instructor Time	74,366.73
C-5A Costs		**Aircraft Use Costs**	
Aircraft Use Cost	$3,411,780.00	C-141	1,468,400.25
Courseware	542.20	C-5	685,773.84
Instructor Time	41,071.65		
C-5 Total	$3,453,393.85		
Total Cost			
C-141 + C-5A Training	$10,903,425.04		$2,291,391.74

Discussion of Training Costs. The cost comparisons clearly show the training value of the low-cost system for FSAS initial training. The use of a microcomputer for FSAS training is a prime example of timely and efficient technology application. The cost benefit ratio is 4.76 to 1. This cost differential is accounted for in the saving of time that would otherwise be required to train personnel in the aircraft on the ground. The overall cost avoidance potential of the microcomputer version of FSAS training as applied to training of current C-141 and C-5A aircrews in FSAS basic procedures is $8,612,033.30.

One additional explanation is in order about alternative ground-based training. The original FSAS procurement plan provided for training using table-top trainers. These were to be composed of trainer-specific components (cables, fan, power converter, brackets, programs, and documentation) and aircraft components (FSAS control display units and computer). The aircraft

components would simply be FSAS system spares. During the procurement process, because of funding difficulties, provision for these training components was cancelled. The only remaining alternative was to perform training in FSAS-equipped aircraft. For purposes of comparison, however, the estimated costs associated with training using an hypothetical trainer are included in Appendix B under Method 3.

IV. DISCUSSION/CONCLUSIONS

The purpose of the present experiment was to evaluate a low-cost, microcomputer-based avionics simulation as a substitute for aircraft-based training. Specifically, it was intended to establish transfer-of-training effectiveness as a basis for cost benefit determination.

The results of the experiment clearly demonstrate the microcomputer-based training to be equivalent to training in the aircraft (with instructor) as measured by training time required to achieve proficiency on eight FSAS procedural tasks. A one-to-one replacement cost ratio is, therefore, justified in comparing the cost of the two training methods. The effectiveness of the experimental training is further supported by the obtained task proficiency ratings. The experimental group achieved proficiency ratings that were reliably higher across the eight tasks than those achieved by the control group.

At least three factors contribute to the effectiveness of the microcomputer-based FSAS training: (a) capability of the microcomputer as a vehicle for both simulation and instruction, (b) software development by a non-programmer subject-matter expert, and (c) replacement of both the aircraft and aircrew instructor with a low-cost, stand-alone trainer.

1. The Microcomputer as an Avionics Simulator/Trainer. A key factor in the success of the experimental training was the use of the microcomputer to simulate the avionics system. Simulation of FSAS functions made the difference between permitting the student to actually practice tasks as would be done in the aircraft and merely receiving explanations about the tasks. With the microcomputer as teacher/simulator, the student was put "on-task" without being in the actual aircraft. The essential perceptual and cognitive dimensions of the task were preserved in the simulation. Although it is true that the low-cost simulation lacked the tactile or touch fidelity associated with depressing actual FSAS control buttons, the training transfer data bear out that touch fidelity for this task is inconsequential as a determinant of training effectiveness. This finding is consistent with those of a similar study (Pohlman & Edwards, 1983) in which graphics display was successfully substituted for actual cockpit symbols and pushbutton switches. Massey's (1985) findings are also consistent in this regard. A reasonable explanation of these findings is that the essential elements of such procedural tasks are perceptual and cognitive rather than psychomotor in nature.

Real-time simulation of the FSAS system (flying environment) was beyond the scope of present requirements of FSAS basic procedures training. However, real-time flight simulation of FSAS operations is potentially deliverable via a microcomputer. This is a possibility MAC and other Air Force users might well pursue for a variety of similar procedural tasks.

2. Software Development. A significant element in the development and cost effectiveness of the trainer was that the software was authored by a subject-matter expert who had no computer programming experience. This was made possible by using the G-TEACHER authoring system developed at HQ MAC/DOT and represented substantial cost savings over the development of software using a professional programmer who would have required special training in FSAS functions and operations in order to develop the instructional materials.

The G-TEACHER system was well suited for the development of FSAS training material. It is not as sophisticated or powerful as many courseware authoring systems currently available. In the present case, however, the lack of complexity was a virtue. The work of authoring computer-based instruction is roughly analogous to the use of word processing software. A general rule applies: The more power (capability) the system offers to the user, the more effort required to learn to use the system. G-TEACHER is a fairly simple system to learn and use. It provides the subject-matter expert who has no computer programming skills with a ready tool for developing instructional materials. It does not automatically ensure instructional quality, of course, but the nature of the training task for FSAS is very explicit. The basic operations of FSAS are straightforward behaviorally. The training objective was clear: Teach the student to perform each of the eight procedural tasks in logical order, permit him to practice each task, and provide adequate feedback to confirm proficiency. The capabilities of G-TEACHER to provide all of these components were very satisfactory. A more costly authoring system, if available, might have been used, assuming the investment of time by the subject-matter expert to learn its use, but it would not necessarily have provided more effective training. G-TEACHER warrants wider application in contexts similar to that of the present study.

3. Replacement of Instructor Time. Next to the cost of the training equipment itself, the greatest cost difference is accounted for by the fact that the experimental system required no instructor except for time in the aircraft to verify task proficiency. The cost of the G-TEACHER computer courseware, which can tutor a student, is much less than aircraft instructor costs, and the courseware development cost can be quickly absorbed. In this sense, the microcomputer becomes not only an effective instructor, but also an extremely cheap one.

The outcomes of the present study present an exemplary application of microcomputer-aided aircrew training. The empirical findings show the experimental device to be at least the equivalent of the aircraft in terms of training time to criterion proficiency. Moreover, the experimental group actually exceeded the standard for proficiency across the eight tasks, as indicated by the mean task ratings. Student automony of the learning experience, combined with free play and feedback on tasks, may in this case account for the superiority of the experimental group in exceeding proficiency requirements.

The present findings underscore the importance of the microcomputer and its potential impact on aircrew training for selected tasks. They clearly show that the appropriate matching of task characteristics with low-cost training systems has large-scale cost savings potential. Aircrew training managers and decision makers are encouraged to exploit this potential in their programs.

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APPENDIX A: TRAINER TRYOUT QUESTIONNAIRE

Rate the quality of the training provided in this program by answering each of the questions below as indicated.

1. How easy or hard was the trainer to use? Rate the ease of use of each of the following features by inputting a number from one to five as indicated on the scale for each item.

Ease of use	Very Hard				Very Easy
Text Information	1	2	3	4	5
Light Pen	1	2	3	4	5
Keyboard	1	2	3	4	5
Graphic Displays	1	2	3	4	5

2. How useful was the trainer? Rate the usefulness of the trainer to train each of the basic FSAS operations by selecting a number from one to five on the scale provided.

Trainer usefulness for FSAS tasks	Not Useful				Very Useful
Basic Information	1	2	3	4	5
FSAS/INS Functions	1	2	3	4	5
INS Mode Keys and Functions	1	2	3	4	5
LOAD Mode Functions	1	2	3	4	5
NAV Mode Functions	1	2	3	4	5
FLT Mode Functions	1	2	3	4	5
PLAN Mode Functions	1	2	3	4	5
RADAR Display Functions	1	2	3	4	5

3. How much training did you get on the trainer for FSAS operations? Rate the amount of training provided for each function by selecting a number from 1 to 5 on the scale provided.

How much training provided for	Not Enough				Too Much
Basic Information	1	2	3	4	5
FSAS/INS Functions	1	2	3	4	5
INS Mode Keys and Functions	1	2	3	4	5
LOAD Mode Functions	1	2	3	4	5
NAV Mode Functions	1	2	3	4	5
FLT Mode Functions	1	2	3	4	5
PLAN Mode Functions	1	2	3	4	5
RADAR Mode Functions	1	2	3	4	5

4. How useful do you think this kind of trainer would be to teach other similar types of tasks?

Usefulness for training other tasks	Not Useful				Very Useful
	1	2	3	4	5

End of questionnaire - thank you.

APPENDIX B: COST DATA DOCUMENTATION

The data supplied in this appendix were furnished from sources within MAC as compiled by Capt Frank Murray. Standard costs documented in the first section below are applied using a cost calculation formula so that equivalence of factors is maintained across the three training methods being compared: Method 1, Aircraft; Method 2, Special Function Trainer (Microcomputer System); and Method 3, Table-Top Trainer (Aircraft spares as ground trainer). The assumptions and rationale for applying the standard cost data are discussed under each training method.

STANDARD COSTS

Electricity Cost

Electricity cost is estimated at $0.10 per kilowatt-hour.

Source: 63rd Avionics Maintenance Squadron FSAS Project Officer.

Manpower Cost

Manpower cost - $56,391.00 per year (standard cost for rated officer) divided by 2,080 hours per year = $27.11 per hour.

Source: AFR 173-13, 1 Feb 85. Annual rate from Table 3.5, divisor from Chapter 3.

Number of Aircrew Members to Train

The number of crew members requiring initial FSAS training is equal to the population of aircrew members in the active and reserve flying units plus crew members attached to those units for flying purposes.

C-141 Crew members = 4,247
C-5A Crew members = 1,212
Total Crew members = 5,459

Source: Chief, Operations Systems Management, HQ MAC/DOTM.

Training Hours

A standard factor of 2.5 hours per session is assumed for comparison of the methods of instruction. Students are assumed to be trained in pairs, using one instructor when an instructor is required by the training method. Training normally requires slightly less than 2.5 hours, but a 2.5-hour block was used as a reasonable rounded figure for scheduled training considerations and cost calculations. The 2.5-hour estimate is consistent with training time requirements reported in this study.

Total FSAS Training Hours Required. For C-141 aircrew training, 4,247 crew members times 2.5 hours of instruction per student divided by two students per training session = 5,309 trainer hours. For C-5A aircrew training, 1,212 crew members times 2.5 hours of instruction per student divided by two students per training session = 1,515 trainer hours required. (Total trainer hours required for C-141 and C-5A = 6,824 hours.)

Instructor Hours. The ratio of one instructor hour per trainer hour is assumed (if instructor is required by the training method).

Source: FSAS Project Officer, 14th MASD/DOT.

COST CALCULATIONS

Only costs which differ between the training methods are included in the cost calculations. Costs that are the same for each method (scheduling, record-keeping, classroom lecture, student manpower) are thus omitted as factors for calculation.

Cost Variables Used in Calculations

AC = Acquisition cost
OC = Operating and maintenance cost (hourly)
TH - Trainer hours (5,309 plus 1,515)
CC = Courseware cost
IH = Instructor hours (same as TH)
MC = Manpower cost (hourly = $27.11)
PS = Per student aircraft cost
NS = Number of students

Calculations. The general formula for cost calculation is:

Cost = AC = (TH x OC) = CC (IH x MC)

The cost calculation for Training Method 1 (Aircraft) differs in the hardware cost. Cost of training in the aircraft is computed on a per-student basis, rather than an hourly basis, resulting in the following equations:

Cost (C-141) = (NS x PS) + CC + (IH x MC)

Cost (C-5A) = (NS x PS) + CC + (IH x MC)

TRAINING METHOD 1 (AIRCRAFT)

Hardware Cost

Acquisition, operation, and maintenance costs of training in FSAS-equipped aircraft are not relevant to training cost considerations since those costs are not attributable to training.

However, an understanding of MAC policy on use of aircraft for ground-based training is essential as a basis for cost comparisons. MAC's operating budget comes from the Airlift Service Industrial Fund (ASIF). To replenish the ASIF, MAC uses its aircraft to generate revenue by "renting" or otherwise charging for aircraft use by DOD and other agencies. When aircraft are

not available for airlift services, users must contract for commercial services at higher rates, and MAC must obtain additional Congressional appropriations to continue its operations. Thus, non-revenue-producing usage of aircraft, even for MAC's own activities, is accounted for as lost opportunity for revenue. A cost formula, specifically derived for non-revenue use of aircraft, is applied. The use of aircraft for ground-based training is considered non-revenue-producing activity and is charged accordingly. This cost is calculated on an hourly basis with a "not-to-exceed" ceiling for a 24-hour period. For example, for the C-141, the hourly charge is $3,125.00, not to exceed $10,321.00 per 24-hour period. Obviously, considering the number of students to be trained on the FSAS, the per-day rather than per-hour rate is more advantageous. The number of students trained per day (allowing for estimated training time and reasonable scheduling efficiency) is divided into the ceiling cost of the aircraft per day to derive the hardware cost per student. Note that the cost for training in an aircraft varies with the type of aircraft.

Hardware Cost - C-141: $3,125.00 per hour, not to exceed $10.321.00 per 24-hour period.

C-5A: $7,770.00 per hour, not to exceed $16,890.00 per 24-hour period.

Source: Chief, Cost and Economic Analysis Division, HQ MAC.

Accounting for the normal availability of aircraft and crew members for training, an average of six students per training day per aircraft can be expected. The following per-student aircraft cost results:

Per-student hardware cost - $10,321 divided by 6 = $1,720.17 per C-141 student; $16,890 divided by 6 = $2,815.00 per C-5A student.

Source: MAC FSAS Training Project Officer, 14th MAS/DOT.

Courseware Cost. Courseware development cost would involve the creation of a lesson plan to be used by the instructor while training the student using the table-top trainer. The lesson plan for this training option would be the same as that used for training using FSAS spare equipment in a ground-based, part-task trainer.

Courseware cost - 20 instructor hours time $27.11 (rated officer hourly rate) = $542.20.

Instructor Cost

The instructor cost for aircraft training is computed on an hourly basis at instructor hour per trainer hour. The hourly rate is based on the standard cost of a rated officer ($27.11 per hour).

Cost Calculation

The training cost calculation for the aircraft method of training is as follows:

Cost (C-141) = (NS x PS) + CC + (IH x MC)
Cost (C-141) = (4,247 x $1,720.17) + $542.20 + (5,309 x $27.11)
Cost (C-141) = $7,450,031.19

Cost (C-5A) = (NS x PS) + CC + (IH x MC)
Cost (C-5A) = (1,212 x $2,815.00) + $542.20 + (1,515 x $27.11)
Cost (C-5A) = $3,453,393.85
Total Cost Both Aircraft = $10,903,425.04

METHOD 2 (MICROCOMPUTER SPECIAL FUNCTION TRAINER)

Hardware Cost

Acquisition Cost. Seven sets of hardware were purchased to support the FSAS training program: one each for four C-141 Wings, one for the C-5A Wing, one each for two mixed C-141/C-5A Wings. One set of hardware, owned by HQ MAC prior to the development of FSAS training, was designated a development and spare trainer to support the effort. The microcomputer-based special function trainer is a programmable device and not intended to be used only for FSAS training. Upon completion of FSAS training, the trainers will continue to be used for aircrew training. Therefore, the acquisition cost of hardware should be amortized over several training projects. The number and duration of future training programs are unknown at present, and the cost of the hardware is amortized only over the present FSAS project. Thus, the cost of equipment acquisition is overstated for this training method:

Cost per set of trainer hardware: $ 7,200.00

Cost for seven sets of training hardware: $50,400.00

Source: HQ MAC/DOT message. On file at 63MAW/DOT.

Operating and Maintenance Cost

The operating cost of the trainers is based on the cost of electricity used to power equipment, the cost of floppy discs replacement, and the maintenance requirements for the equipment, based on experience accrued with the first system placed in operation. The exact power consumption is not available but is estimated to be 443 watts based on the maximum current ratings of all system components. Floppy discs require replacement typically after 200 hours of use on the special function trainer.

Electricity - .443 kilowatt x $.10 per kilowatt hour = $0.0443 per trainer hour.

Floppy disc cost - $1.80 per disc divided by 200 hours per disc = $0.009 per trainer hour.

Maintenance cost - $500.00 per 1,000 hours of operation = $.50 per trainer hour.

Operation/Maintenance Cost - $0.5533 per trainer hour.

Courseware Costs

A rated officer, inexperienced in computer programming, produced the courseware for the special function trainer. Part of his time was spent in learning to use G-TEACHER, the authoring language used for courseware development. This represents a one-time cost for each courseware author. This one-time cost has been included which overstates the cost of this training method for the FSAS application. Phases of development are as shown:

Familiarization with Software:	40 hours x $27.11 =	$1,084.40
Production of FSAS lessons:	240 hours x $27.11 =	6,506.40
Revision of lessons:	40 hours x $27.11 =	1,084.40
Total Cost of Courseware		$8,675.20

Source: MAC FSAS courseware author, 14MAS/DOT.

Instructor Cost

FSAS training via the microcomputer-based special function trainer precluded the requirement for a live instructor, except for the time in the aircraft used to verify proficiency on the actual equipment. The average time per student required to demonstrate proficiency in the experiment was 30.15 minutes. The calculation of instructor cost, therefore, is: 30.15 minutes (.5025 hour) x MC ($27.11) x NS (5,459) = $74,366.73

Aircraft Use Cost

The cost of proficiency verification testing in the aircraft is calculated based upon the per-student cost of aircraft training. The students trained in the aircraft required 2.5 hours of training. In the C-141, the per-student cost was $1,720.17, or $688.07 per hour. The cost derivation for the testing of Method 2 trainees is: 30.15 minutes (.5025 hour) x $688.07 = $345.75 per student. Using the same derivation for the C-5A rate, the cost is $565.82 per student. The cost of testing applied across current aircrews is:

C-141 costs: 4,247 students x $345.75 =	$1,468,400.25
C-5A costs: 1,212 students x $565.82 =	685,773.84
Total aircraft use cost for testing: =	$2,154,174.09

Cost of Training (Method 2)

Hardware	$50,400.00
Courseware	8,675.20
Operating/Maintenance	3,775.72
Instructor	74,366.73
Aircraft Use Cost	2,154,174.09
Total	$2,291,391.74

METHOD 3 (TABLE-TOP TRAINER)

Cost estimates for this method of training are documented as shown. However, the training method itself is hypothetical since table-top trainers are not available. Estimates are presented here for cost comparison information only. Under provisions of the original FSAS procurement plan, extra FSAS components were to have been provided as spares for ground training. However, when funding was reduced, this provision of the procurement was cancelled, precluding this training option.

Hardware Cost

Acquisition Cost. The table-top trainer would consist of two types of components: trainer-specific (cables, fan, power converter, brackets, programs, and documentation) and aircraft components (FSAS control/display unit and computer). The trainer-specific components would not be suitable for other uses following FSAS training and would be discarded. The cost of the trainer-specific components, therefore, would be directly attributable to training. The aircraft components would be purchased in addition to those otherwise required. After training, however, aircraft components could be used as additional spares. Since the additional spares

would not be part of the identified logistics requirement, their cost is attributable entirely to training. The cost of trainers is calculated based on the same number of special function trainers shown in Method 2 (seven trainers).

Trainer-Specific Components - $36,190 x 7 = $253,330.00

Aircraft-Specific Components - $44,700 x 7 = $312,900.00

Total Hardware Acquisition Cost $566,230.00

Source: C-141 FSAS Program Manager, WR-ALC/MMSH

Operating and Maintenance Cost

Hardware operating cost is limited to electricity used to power the components during the training. An exact power consumption rate is not available but is estimated to be 2,220 watts. Hardware maintenance cost is not available but could be expected to be significant since all components would be of new design. Components of this type typically exhibit high failure rates early in their life cycles until the design "matures."

Operating Cost: 2.220 kilowatts x $.10 per kilowatt hour = $0.222 per trainer hour.

Maintenance Cost: Unknown. Assumed to be zero which understates the cost of this method.

Source: FSAS Systems Manager, 63rd Avionic Maintenance Squadron. (FSAS table-top trainer current used estimated to be 17 to 20 amps).

Courseware Cost

Courseware development cost would involve the creation of a lesson plan and would be equivalent to that of Method 1 (Aircraft Training).

Courseware Cost: 20 instructor hours x $27.11 per hour = $542.20

Source: MAC FSAS Training Project Officer, 63MAS/DOT.

Instructor Cost

Instructor cost for this method is computed on the same hourly basis as for Method 1; i.e., $27.11 per hour.

Cost Calculation

(Costs are totaled for both C-141 and C-5A FSAS Training).

Cost (Table-top training) = AC + (TH x OC) + CC + (IH x MC)

Cost = $566,230.00 + (6,824 x $.222) + $542.20 + 6,824 x $27.11)

Cost (Table-top training) = $753,285.77

SUMMARY OF COSTS

The total cost of FSAS training via each of the methods elaborated in this appendix is shown below. The cost includes FSAS training for both C-141 and C-5A aircrews.

Method 1 (Aircraft)	$10,903,425.04
Method 2 (Microcomputer-based trainer)	$ 2,291,391.74
Method 3 (Table-top trainer)	$ 753,285.77

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